

# Physics Notes Class 11 CHAPTER 13 KINETIC THEORY

## Assumptions of Kinetic Theory of Gases

1. Every gas consists of extremely small particles known as molecules. The molecules of a given gas are all identical but are different from those of another gas.
2. The molecules of a gas are identical spherical, rigid and perfectly elastic point masses.
3. Their molecular size is negligible in comparison to intermolecular distance ( $10^{-9}$  m).
4. The speed of gas molecules lies between zero and infinity (very high speed).
5. The distance covered by the molecules between two successive collisions is known as free path and mean of all free path is known as mean free path.
6. The number of collision per unit volume in a gas remains constant.
7. No attractive or repulsive force acts between gas molecules.
8. Gravitational to extremely attraction among the molecules is ineffective due small masses and very high speed of molecules.

## Gas laws

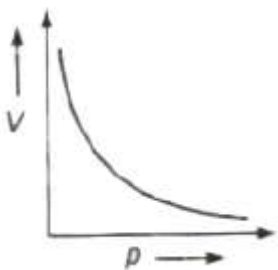
Assuming permanent gases to be ideal, through experiments, it was established that gases irrespective of their nature obey the following laws.

### Boyle's Law

At constant temperature the volume (V) of given mass of a gas is inversely proportional to its pressure (p), i.e.,

$$V \propto 1/p \Rightarrow pV = \text{constant}$$

For a given gas,  $p_1 V_1 = p_2 V_2$



### Charles' Law

At constant pressure the volume (V) of a given mass of gas is directly proportional to its absolute temperature (T), i.e.,

$$V \propto T \Rightarrow V / T = \text{constant}$$

For a given gas,  $V_1/T_1 = V_2/T_2$

At constant pressure the volume (V) of a given mass of a gas increases or decreases by  $1/273.15$  of its volume at  $0^\circ\text{C}$  for each  $1^\circ\text{C}$  rise or fall in temperature.

Volume of the gas at  $t^\circ\text{C}$

$$V_t = V_0 (1 + t/273.15)$$

where  $V_0$  is the volume of gas at  $0^\circ\text{C}$ .

### **Gay Lussacs' or Regnault's Law**

At constant volume the pressure  $p$  of a given mass of gas is directly proportional to its absolute temperature  $T$ , i.e. ,

$$p \propto T \Rightarrow p/T = \text{constant}$$

For a given gas,

$$p_1/T_1 = p_2/T_2$$

At constant volume (V) the pressure  $p$  of a given mass of a gas increases or decreases by  $1/273.15$  of its pressure at  $0^\circ\text{C}$  for each  $1^\circ\text{C}$  rise or fall in temperature.

$$\text{Volume of the gas at } t^\circ\text{C}, p_t = p_0 (1 + t/273.15)$$

where  $P_0$  is the pressure of gas at  $0^\circ\text{C}$ .

### **Avogadro's Law**

Avogadro stated that equal volume of all the gases under similar conditions of temperature and pressure contain equal number molecules. This statement is called Avogadro's hypothesis.

According Avogadro's law

(i) Avogadro's number The number of molecules present in 1g mole of a gas is defined as Avogadro's number.

$$N_A = 6.023 \times 10^{23} \text{ per gram mole}$$

(ii) At STP or NTP ( $T = 273 \text{ K}$  and  $p = 1 \text{ atm}$ ) 22.4 L of each gas has  $6.023 \times 10^{23}$  molecules.

(iii) One mole of any gas at STP occupies 22.4 L of volume.

### **Standard or Perfect Gas Equation**

Gases which obey all gas laws in all conditions of pressure and temperature are called perfect gases.

Equation of perfect gas  $pV=nRT$

where  $p$  = pressure,  $V$  = volume,  $T$  = absolute temperature,  $R$  = universal gas constant and  $n$  = number of moles of a gas.

Universal gas constant  $R = 8.31 \text{ J mol}^{-1}\text{K}^{-1}$ .

### **Real Gases**

Real gases deviate slightly from ideal gas laws because

- Real gas molecules attract one another.
- Real gas molecules occupy a finite volume.

### **Real or Van der Waal's Gas Equation**

$$(p + a/V^2)(V - b) = RT$$

where  $a$  and  $b$  are called van der Waals' constants.

Pressure due to an ideal gas is given by

$$p = (1/3).(mn/V).c^2 = 1/3 \rho c^2$$

For one mole of an ideal gas

$$P = (1/3).(M/V).c^2$$

where,  $m$  = mass of one molecule,  $n$  = number of molecules,  $V$  = volume of gas,  $c = (c_1^2 + c_2^2 + \dots + c_n^2) / n$  all the root mean square (rms) velocity of the gas molecules and  $M$  = molecular weight of the gas. If  $p$  is the pressure of the gas and  $E$  is the kinetic energy per unit volume is  $E$ , then

$$p = (2/3).E$$

### **Kinetic Energy of a Gas**

(i) Average kinetic energy of translation per molecule of a gas is given by

$$E = (3/2) kt$$

where  $k$  = Boltzmann's constant.

(ii) Average kinetic energy of translation per mole of a gas is given by

$$E = (3/2) R t$$

where  $R$  = universal gas constant.

(iii) For a given gas kinetic energy

$$E \propto T \Rightarrow E_1/E_2 = T_1/T_2$$

(iv) Root mean square (rms) velocity of the gas molecules is given by

$$c = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3p}{\rho}}$$

(v) For a given gas  $c \propto \sqrt{T}$

(vi) For different gases  $c \propto 1/\sqrt{M}$

(vii) Boltzmann's constant  $k = R/N$

where  $R$  is ideal gas constant and  $N$  = Avogadro number.

Value of Boltzmann's constant is  $1.38 \times 10^{-28}$  J/K.

(viii) The average speed of molecules of a gas is given by

$$\bar{v} = \sqrt{\frac{8kT}{\pi m}} = \sqrt{\frac{8RT}{\pi M}}$$

(ix) The most probable speed of molecules of a gas is given by

$$v_{mp} = \sqrt{\frac{2kT}{m}} = \sqrt{\frac{2RT}{M}}$$

⇒

$$v_{rms} > \bar{v} > v_{mp}$$

### Important Points

- (i) With rise in temperature rms speed of gas molecules increases as

$$v_{rms} \propto \sqrt{T}$$

- (ii) With the increase in molecular weight rms speed of gas molecule decrease as

$$v_{rms} \propto \frac{1}{\sqrt{M}}$$

- (iii) Rms speed of gas molecules is of the order of km/s, e.g., at NTP for hydrogen gas

$$v_{rms} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3 \times 8.31 \times 273}{2 \times 10^{-3}}}$$

- (iv) Rms speed of gas molecules does not depend on the pressure of gas (if temperature remains constant) because  $p \propto \rho$  (Boyle's law). If pressure is increased  $n$  times, then density will also increase by  $n$  times but  $v_{rms}$  remains constant.

### Degree of Freedom

The degree of freedom for a dynamic system is the number of directions in which it can move freely or the number of coordinates required to describe completely the position and configuration of the system.

It is denoted by  $f$  or  $N$ .

Degree of freedom of a system is given by

$$f \text{ or } N = 3A - R$$

where  $A$  = number of particles in the system and  $R$  = number of independent relations.

### Degree of Freedom

1. For monoatomic gas = 3
2. For diatomic gas = 5
3. For non-linear triatomic gas = 6
4. For linear triatomic gas = 7

Specific heat of a gas

(a) At constant volume,  $C_V = f/2 R$

(b) At constant pressure,  $c_p = (f/2 + 1)R$

(c) Ratio of specific heats of a gas at constant pressure and at constant volume is given by  
 $\gamma = 1 + 2/f$

### **Mean Free Path**

The average distance travelled by a molecule between two successive collisions is called mean free path ( $\gamma$ ).

Mean free path is given by

$$\gamma = kT / \sqrt{2} \pi \sigma^2 p$$

where  $\sigma$  = diameter of the molecule,  $p$  = pressure of the gas,  
 $T$  = temperature and  $k$  = Boltzmann's constant.

Mean free path

$$\lambda \propto T \text{ and } \lambda \propto 1/p$$

### **Brownian Motion**

The continuous random motion of the particles of microscopic size suspended in air or any liquid, is called Brownian or microscopic motion.

Brownian suspended motion in both is observed with many liquids and gases.

Brownian motion is due to the unequal bombardment of the suspended Particles by the molecules of the surrounding medium.